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**14. ABSTRACT**

Based on the theory of locally optimum detection we identified a spread-spectrum receiver architecture that consists of an adaptive non-linear chip-level pre-processor followed by an adaptive linear filter post-processor. The non-linear front-end protects against impulsive, non-Gaussian disturbance. The adaptive linear filter post-processor suppresses unknown highly correlated spread-spectrum (SS) interference. To achieve adaptive, rapid, and effective SS interference suppression from a small number of input observations, we defined a new class of linear filters that we called Auxiliary-Vector (AV) filters. We view this development as a breakthrough in the field of adaptive signal processing theory. When the input autocorrelation matrix is unknown and estimated from a limited set of input data (as in all real-life adaptive signal processing applications), Auxiliary-Vector filters are shown to outperform all other filter estimator means in the literature. We addressed successfully the critical problem of determining an automated, theoretically derived, rule for the selection of the best number of auxiliary vectors (AV's) for a given data record of input observations. We anticipate that this development will attract a great deal of interest in the Auxiliary-Vector filtering technique. Based on the principles of AV-filtering we proposed and analyzed theoretically structures that are self-synchronized in the sense that adaptive synchronization and demodulation are viewed and treated as an integrated receiver operation. As a major application, we addressed the problem of navigation data demodulation by an adaptive jam-resistant GPS receiver that utilizes a bank of linear-tap-delay filters and employs antenna-array reception (one space-time ''Auxiliary-Vector'' (AV) filter per satellite).

**15. SUBJECT TERMS**

Auxiliary-vector filtering, antenna arrays, adaptive systems, synchronization, spread-spectrum, communications, interference suppression, short data records, GPS.

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# Title
# Robust Spread-Spectrum Communications over non-Gaussian Channels

## Subtitle
## Adaptive Disturbance Suppression with Small Sample Support

TABLE OF CONTENTS

# 1 OBJECTIVES

This research focused on the design of novel, fully adaptive spread-spectrum (SS) receivers that have the ability to suppress unknown highly correlated spread- spectrum interference and impulsive (non-Gaussian) disturbances. What characterizes uniquely this effort is the objective to design receivers with superior, state-of-the-art, short-data-record adaptive performance (that is, rapid, effective interference suppression through very limited input observations).

Target applications included: *(i)* Robust, time-domain adaptive SS receivers. *(ii)* Robust, joint space-time domain adaptive SS receivers with antenna arrays. *(iii)* Jam-resistant adaptive GPS (Global-Positioning-System) receivers with or without antenna array reception.

The unique ability to suppress effectively and rapidly unknown interference with limited input data makes these developments ideal for cockpit instrumentation.

# 2 SUMMARY OF RESEARCH EFFORT

The milestones reached during the first year of the research project are as follows. Theoretical studies and analysis led to the receiver architecture that consists of *(i)* a non-linear parametrically described front-end operating at the chip signal level, followed by *(ii)* a linear filter post-processor. The non-linear front-end was seen to offer effective protection from impulsive, non-Gaussian disturbances. The linear filter post-processor offers effective suppression of spread-spectrum (SS) interference.

A novel decision driven Minimum-Bit-Error-Rate recursive algorithm was developed for the on-line adaptation (optimization) of the cut-off parameters of the non-linear pre-processor. For the linear filter post-processor, a whole new class of filters was developed (that we call Auxiliary-Vector filters) to achieve state-of-the-art, rapid, short-data-record adaptive SS interference suppression. A brief summary of this development, that we consider a breakthrough in the context of adaptive signal processing theory, is given in the next section of this progress report.

Numerical and simulation studies of this adaptive SS receiver confirmed our theoretical state-of-the-art performance claims. The studies included both time-domain-only processing and space-time processing through antenna array reception. An important issue that remained to be tackled was

the development of an automated, theoretically derived, rule-of-thumb for the selection of the best number of auxiliary vectors for a given number of input observations. A development of this sort would attract a great deal of interest in Auxiliary-Vector filtering wherever practical adaptive signal processing is involved.

The milestones reached during the second year of the research project are as follows.

*(i)* We developed and analyzed blind adaptive linear receivers for the demodulation of DS/SS signals in asynchronous transmissions. The proposed structures are self-synchronized in the sense that adaptive synchronization and demodulation are viewed and treated as an integrated receiver operation.

*(ii)* We investigated theoretically the coarse synchronization performance of blind adaptive linear self-synchronized receivers for asynchronous direct-sequence spread-spectrum communications under finite data record adaptation. We derived analytic expressions that approximate the probability of coarse synchronization error of matched-filter-type (MF) and minimum-variance-distortionless-response-type (MVDR) receivers based on transformation noise modeling techniques.

*(iii)* We investigated theoretically the data-record-size requirements of MVDR-type adaptive algorithms to meet a given performance objective in joint space-time signal detection and direction-of-arrival (DoA) estimation problems for direct-sequence spread-spectrum systems. We derived closed form expressions that provide the data record size that is necessary to achieve a given performance confidence level in a neighborhood of the optimal performance point, as well as expressions that identify the performance level that can be reached for a given data record size.

*(iv)* As a major application, we addressed the problem of navigation data demodulation by an adaptive GPS receiver that utilizes a bank of single-satellite linear-tap-delay filters and employs antenna-array reception.

*(v)* We addressed successfully the critical problem that we identified during the first year of the project. This is the problem of determining an automated theoretically derived rule for the selection of the best number of auxiliary vectors for a given data record of input observations.

*(vi)* We developed and analyzed differential modulation and phase recovery algorithms for spread-spectrum communications.

In future work there are two important issues that remain to be tackled which are identified below. *(i)* On-line adaptation of the parametric receiver front-end non-linearity in the absence of a known bit preamble of the SS

signal of interest. *(ii)* Theoretical finite-sample-support distribution analysis of the auxiliary vector filter estimators.

# 3 ACCOMPLISHMENTS/NEW FINDINGS

During the first year of this project, based on the theory of locally optimum detection we identified a spread-spectrum receiver architecture that consists of a non-linear chip-level pre-processor followed by linear filter post-processing [4].

For adaptive protection against a broad range of unknown non-Gaussian disturbances we installed a parametric non-linearity that encompasses previously considered non-linearities (punchers, clippers etc.) as special cases [1],[8],[12],[13],[15]. This parametric non-linearity meets exceptionally well our requirements for *(i)* low computational/ hardware complexity and *(ii)* effective system adaptation through limited input observations. A novel decision driven Minimum-Bit-Error-Rate recursive algorithm was developed for the on-line optimization (adaptation) of the parametrically described non-linearity [3].

The non-linear front-end protects against impulsive, non-Gaussian disturbance. The adaptive linear filter post-processor suppresses unknown highly correlated spread-spectrum (SS) interference. To achieve adaptive, rapid, and effective SS interference suppression from a small number of input observations, we had to define a new class of linear filters that we called Auxiliary-Vector (AV) filters [1],[2],[4]-[16]. We view this development as a breakthrough in the field of adaptive signal processing theory. A brief technical summary follows. Our filter design procedure starts from the conventional matched filter. Next, we incorporate an orthogonal Auxiliary-Vector component chosen according to the Maximum-Cross-Correlation (MCC) criterion that we introduced in [6]. Based on conditional statistical optimization principles, we generalized inductively our approach in the form of processing with multiple orthogonal to each other Auxiliary Vectors [2]. The orthogonality among AV's was relaxed in [1],[7],[8],[11],[12]. The outcome is a sequence of filters that starts from the matched-filter and, as we proved in [7], converges to the ideal optimum filter when the input autocorrelation matrix is perfectly known. When the input autocorrelation matrix is unknown and estimated from a limited set of input data (as in all real-life adaptive signal processing applications), Auxiliary-Vector filters in our generated sequence are seen to outperform all other filter estimator means that

are known today.

State-of-the-art, rapid, adaptive impulsive and spread-spectrum interference suppression using only a small number of input observations, makes our developments ideal for cockpit instrumentation and battlefield communication systems implementation.

For civilian applications, protection from non-Gaussian disturbances is not an issue of primary concern. However, rapid adaptive SS interference suppression through the use of our newly developed Auxiliary-Vector filters is of major importance for wireless DS/CDMA communications over multipath fading channels.

Specific applications considered during the first year of our project include: DS/CDMA communications over multipath fading channels [6], antenna array DS/CDMA receivers [2], DS/CDMA receiver synchronization [9],[10],[14],[16], robust SS receivers with antenna arrays [8],[13].

During the second year of this project, we considered blind adaptive linear receivers for the demodulation of DS/SS signals in asynchronous transmissions. The proposed structures are self-synchronized in the sense that adaptive synchronization and demodulation are viewed and treated as an integrated receiver operation. Two computationally efficient *combined* synchronization/demodulation schemes were proposed, developed and analyzed [9],[16]. The first scheme is based on the principles of minimum-variance-distortionless-response (MVDR) processing, while the second scheme follows the principles of auxiliary-vector filtering and exhibits enhanced performance in short data record scenarios. In both cases the resulting receiver is a linear structure of order exactly equal to the system processing gain. Simulation studies demonstrated the coarse synchronization, as well as the bit-error-rate performance of the proposed strategies. In addition, we investigated theoretically the coarse synchronization performance of blind adaptive linear self-synchronized receivers for asynchronous direct-sequence code-division-multiple-access communications under finite data record adaptation. We derived [10],[16],[27] analytic expressions that approximate the probability of coarse synchronization error of matched-filter-type (MF) and minimum-variance-distortionless-response-type (MVDR) receivers based on transformation noise modeling techniques. The expressions are explicit functions of the data record size $N$ and the filter order $p$ and reveal the effect of short-data-record Sample-Matrix-Inversion (SMI) implementations on the coarse synchronization performance. Besides their theoretical value, the derived expressions provide simple, highly-accurate alternatives to computationally demanding performance evaluation through simulations. Numer-

ical and simulation studies examined the accuracy of the theoretical developments and showed that the derived expressions approximate closely the actual coarse synchronization performance.

During the second year of this project, we also investigated the data-record-size requirements of minimum-variance-distortionless-response-type adaptive algorithms to meet a given performance objective in joint space-time signal detection and direction-of-arrival (DoA) estimation problems for direct-sequence code-division-multiple-access systems. We derived closed form expressions that provide the data record size that is necessary to achieve a given performance confidence level in a neighborhood of the optimal performance point, as well as expressions that identify the performance level that can be reached for a given data record size [17],[20],[22],[28]. This was done by utilizing close approximations of the involved probability density functions. The practical significance of the derived expressions lies in the fact that the expressions are functions of the number of antenna elements and the system spreading gain only, while they are independent of the ideal input covariance matrix which is not known in most realistic applications.

The presence of the desired signal during the estimation of the minimum-variance-distortionless-response (MVDR) or auxiliary-vector (AV) filter under limited data records leads to significant signal-to-interference-plus-noise ratio (SINR) performance degradation. We quantified this observation in the context of DS/SS communications by deriving two new close approximations for the probability density functions (under both desired-signal-"present" and desired-signal-"absent" conditions) of the output SINR and bit-error-rate (BER) of the sample-matrix-inversion (SMI) MVDR receiver [18],[31],[32]. To avoid such performance degradation we proposed a DS/SS receiver that utilizes a simple pilot-assisted algorithm that estimates and then subtracts the desired signal component from the received signal prior to filter estimation. Then, to accommodate decision directed operation we developed two recursive algorithms for the on-line estimation of the AV and MVDR filter and we studied their convergence properties. Simulation studies illustrated the BER performance of the overall receiver structures.

As a major application during the second year of the project, we addressed the problem of navigation data demodulation by an adaptive GPS receiver that utilizes a bank of single-satellite linear-tap-delay filters and employs antenna-array reception. The presence of an antenna array allows the receiver to operate in the spatial domain in addition to the temporal (code) domain. We investigated disjoint-domain as well as joint-domain space-time GPS signal processing techniques and we considered design criteria

of conventional matched-filter (MF) type, minimum-variance-distortionless-response (MVDR) type and auxiliary-vector (AV) type. The proposed structures utilize filters that operate at a fraction of the navigation data bit period (1 msec) and are followed by hard-decision detectors [19]. Hard decisions taken over a navigation data bit period are then combined according to a simple combining rule for further bit-error-rate (BER) performance improvements. Analytic, numerical and simulation comparisons illustrated the relative merits of the investigated design alternatives.

Finally, we are happy to report that we tackled successfully the practical problem that was identified as a most critical one during the first year of the project. Selecting the most successful (in some appropriate sense) AV filter estimator for a given data record was a problem that had not been addressed so far [24],[26],[29]. We dealt exactly with this problem and we proposed two data driven selection criteria. The first criterion maximizes the estimated J-divergence of the AV-filter-output conditional distributions given the transmitted information bit, while the second criterion minimizes the cross-validated sample average variance of the AV-filter output [33].

Other SS communications issues that we investigated during the second year of the project include differential modulation [23] and phase recovery algorithms [21],[25],[30].

# 4 PERSONNEL SUPPORTED

## a. Year One

Faculty:
S. N. Batalama
D. A. Pados

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I. N. Psaromiligkos
Ping Xiong
Haoli Qian
George Karystinos
Zhenyu Liu
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Ping Xiong
Jeffrey Farrell
Haoli Qian
George Karystinos
Zhenyu Liu

# 5 PUBLICATIONS

(updated as of Mar. 30, 2001)

[1] S. N. Batalama, M. J. Medley, and D. A. Pados, "Robust adaptive recovery of spread-spectrum signals with short data records," IEEE Transactions on Communications, vol. 48, pp. 1725-1731, Oct. 2000.

[2] D. A. Pados and S. N. Batalama, "Joint space-time auxiliary-vector filtering for DS/CDMA systems with antenna arrays," IEEE Transactions on Communications, vol. 47, pp. 1406-1415, Sept. 1999.

[3] I. N. Psaromiligkos, S. N. Batalama, and D. A. Pados, "On adaptive minimum probability of error linear-filter receivers for DS-CDMA channels," IEEE Transactions on Communications, vol. 47, pp. 1092-1102, July 1999.

[4] S. N. Batalama, M. J. Medley, and I. N. Psaromiligkos, "Adaptive robust spread-spectrum receivers," IEEE Transactions on Communications, vol. 47, pp. 905-917, June 1999.

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[6] A. Kansal, S. N. Batalama, and D. A. Pados, "Adaptive maximum SINR RAKE filtering for DS-CDMA multipath fading channels," IEEE Journal on Selected Areas in Communications, vol. 16, pp. 1765-1773, Dec. 1998.

[7] D. A. Pados and G. N. Karystinos, "An iterative algorithm for the computation of the MVDR filter," IEEE Transactions on Signal Processing, vol. 49, pp. 290-300, Feb. 2001.

[8] D. A. Pados, M. J. Medley, and S. N. Batalama, "Adaptive antenna array receivers for spread-spectrum signals in non-Gaussian noise," Digital Signal Processing, Special Issue on Defense Applications of Signal Processing, Academic Press, to appear April 2001.

[9] I. N. Psaromiligkos M. J. Medley and S. N. Batalama, "Rapid synchronization and combined demodulation for DS/CDMA communications. Part

I: Algorithmic developments," IEEE Transactions on Communications, submitted Dec. 1999, accepted for publication pending revisions Jan. 2001.

[10] I. N. Psaromiligkos and S. N. Batalama, "Rapid synchronization and combined demodulation for DS/CDMA communications. Part II: Finite data-record-size performance analysis," IEEE Transactions on Communications, submitted Dec. 1999, accepted for publication pending revisions Jan. 2001.

[11] G. N. Karystinos and D. A. Pados, "On DPSK demodulation of DS/CDMA signals," in Proceedings IEEE GLOBECOM'99, Communications Theory Symposium, Rio de Janeiro, Brazil, Dec. 1999, vol. 5, pp. 2487-2492.

[12] S. N. Batalama, M. J. Medley, and D. A. Pados, "Adaptive robust DS-SS signal processing with short data records," in Proceedings 1999 AIAA Space Technology Conference, Albuquerque, NM, Sept. 1999, and in Proceedings DASP99 Workshop on Defense Applications of Signal Processing, LaSalle, IL, Aug. 1999, pp. 19-24.

[13] D. A. Pados, M. J. Medley, and S. N. Batalama, "Adaptive antenna array receivers for spread-spectrum signals in impulsive noise," in Proceedings SPIE's 13th Annual International Symposium, Digital Wireless Communication Conf., vol. 3708, pp. 118-127, Orlando, FL, April 1999.

[14] I. N. Psaromiligkos, J. D. Matyjas, and S. N. Batalama, "Combined synchronization and demodulation of DS/CDMA signals with short data records," in Proceedings 1999 Conference on Information Sciences and Systems, Johns Hopkins University, Baltimore, MD, March 1999, vol. II, pp. 844-849.

[15] S. N. Batalama, M. J. Medley, and D.A. Pados, "Outlier resistant DS-SS signal processing," in Proceedings Thirty Second Annual Asilomar Conf. on Signals, Systems, and Computers, vol. 1, pp. 573-577, Pacific Grove, CA, Nov. 1998.

[16] I. N. Psaromiligkos and S. N. Batalama, "Blind self-synchronized demodulation of DS-CDMA communications," in Proceedings IEEE International Conf. on Communications (ICC 2000), pp. 949-953, New Orleans, LA, June 2000.

[17] I. N. Psaromiligkos and S. N. Batalama, "Data record size requirements for adaptive space-time DS/CDMA signal detection and direction-of-arrival estimation," IEEE Transactions on Communications, submitted Mar. 2000, currently under review.

[18] I. N. Psaromiligkos and S. N. Batalama, "Recursive AV and MVDR filter estimation for maximum SINR adaptive space-time processing," IEEE Transactions on Communications, submitted July 2000.

[19] P. Xiong, M. J. Medley, and S. N. Batalama, "Spatial and temporal processing for global navigation satellite systems: The GPS receiver paradigm", IEEE Transactions on Aerospace and Electronic Systems, submitted July 2000.

[20] I. N. Psaromiligkos and S. N. Batalama, "Data record size requirements for adaptive space-time DS/CDMA signal detection and direction-of-arrival estimation," in Proceedings 2000 Conference on Information Sciences and Systems, vol. II, pp. FA3.1-FA3.7, Princeton University, Princeton, NJ, March 2000.

[21] G. N. Karystinos and D. A. Pados, "Supervised phase correction of blind space-time DS/CDMA channel estimates," in Proceedings 2000 Conference on Information Sciences and Systems, vol. I, pp. TA8a.5-TA8a.10, Princeton University, Princeton, NJ, March 2000.

[22] I. N. Psaromiligkos and S. N. Batalama, "Data record size requirements for adaptive antenna arrays," in Proceedings SPIE's 14th Annual International Symposium, Digital Wireless Communication Conf., vol. 4045, pp. 122-131, Orlando, FL, April 2000.

[23] G. N. Karystinos and D. A. Pados, "Multiuser differential-PSK demodulators for DS/CDMA signals," in Proceedings SPIE's 14th Annual International Symposium, Digital Wireless Communication Conf., vol. 4045, pp. 155-166, Orlando, FL, April 2000.

[24] J. D. Matyjas and S. N. Batalama, "A regularized MVDR-filter estimator with application to DS/CDMA communications," in Proceedings Intern. Conf. on Telecom. (ICT 2000), vol. 2, pp. 1020-1025, Acapulco, Mexico,

May 2000.

[25] G. N. Karystinos and D. A. Pados, "Recovering the phase of blind space-time DS/CDMA channel estimates," in Proceedings Intern. Conf. on Telecom. (ICT 2000), vol. 2, pp. 1010-1014, Acapulco, Mexico, May 2000.

[26] D. A. Pados and G. N. Karystinos, "A sequence of MVDR filter estimators," in Proceedings Intern. Conf. on Telecom. (ICT 2000), vol. 2, pp. 790-794, Acapulco, Mexico, May 2000.

[27] I. N. Psaromiligkos and S. N. Batalama, "Finite data record performance analysis of rapid synchronization and combined demodulation algorithms," in Proceedings ICASSP 2000 - Intern. Conf. on Acoust., Speech and Signal Proc., vol. V, pp. 2557-2560, Istanbul, Turkey, June 2000.

[28] S. N. Batalama and I. N. Psaromiligkos, "Data record size requirements of MVDR-optimized adaptive antenna arrays," in Proceedings ICASSP 2000 - Intern. Conf. on Acoust., Speech and Signal Proc., vol. V, pp. 3069-3072, Istanbul, Turkey, June 2000.

[29] D. A. Pados and G. N. Karystinos, "Short-data-record estimators of the MVDR/MMSE filter," in Proceedings ICASSP 2000 - Intern. Conf. on Acoust., Speech and Signal Proc., vol. I, pp. 384-387, Istanbul, Turkey, June 2000.

[30] G. N. Karystinos and D. A. Pados, "Supervised phase correction of blind space-time DS/CDMA channel estimates," IEEE Transactions on Communications, submitted March 2000.

[31] I. N. Psaromiligkos and S. N. Batalama, "Finite data record maximum SINR adaptive space-time processing," in Proceedings IEEE SSAP 2000 - Workshop on Statistical Signal and Array Proc., pp. 677-681, Pocono Manor Inn, Pocono Manor, PA, Aug. 2000.

[32] I. N. Psaromiligkos and S. N. Batalama, "Interference-plus-noise covariance matrix estimation for adaptive space-time processing of DS/CDMA signals," in Proceedings IEEE VTC 2000 - Vehicular Tech. Conf., vol. 5, pp. 2197-2204, Boston, MA, Sept. 2000.

[33] H. Qian and S. N. Batalama, "Data-record-based criteria for the selection of an auxiliary-vector estimator of the MVDR filter," in Proceedings Thirty Fourth Annual Asilomar Conf. on Signals, Systems, and Computers, vol. 1, pp. 802-807, Pacific Grove, CA, Oct. 2000.

# 6 INTERACTIONS/TRANSITIONS

**I. Participation/presentations at meetings, conferences**

1. S. N. Batalama, "Robust adaptive recovery of spread-spectrum signals with short data records," participation/presentation at 1999 Workshop on Defense Applications of Signal Processing, Starved Rock Conference Center, LaSalle, IL, Aug. 22-27, 1999.

2. S. N. Batalama, "Adaptive robust spread-spectrum receivers and their application to GPS," participation/presentation at AFOSR Contractors' Meeting and Technical Review, Minnowbrook Conference Center, Blue Mountain Lake, NY, Apr. 14-16, 1999.

3. M. J. Medley, "Adaptive robust DS-SS signal processing with short data records," participation/presentation at 1999 AIAA Space Technology Conference, Albuquerque, NM, Sept. 28-30, 1999.

4. D. A. Pados, "Adaptive antenna array receivers for spread-spectrum signals in impulsive noise," participation/presentation at SPIE's 13th Annual International Symposium, Digital Wireless Communication Conference, Orlando, FL, April 1999.

5. I. N. Psaromiligkos, J. D. Matyjas, and S. N. Batalama, "Combined synchronization and demodulation of DS-CDMA signals with short data records," participation/presentation at 1999 Conference on Information Sciences and Systems, Johns Hopkins University, Baltimore, MD, March 1999.

6. S. N. Batalama and D.A. Pados, "Outlier resistant DS-SS signal processing," participation/presentation at Thirty Second Annual Asilomar Conference on Signals, Systems, and Computers, Pacific Grove, California, Nov. 1998.

7. I. N. Psaromiligkos and S. N. Batalama, "Data record size requirements for adaptive space-time DS/CDMA signal detection and direction-of-arrival estimation," participation/presentation at 2000 Conference on Information Sciences and Systems, Princeton University, Princeton, NJ, Mar. 15-17 2000.

8. G. N. Karystinos and D. A. Pados, "Supervised phase correction of blind space-time DS/CDMA channel estimates," participation/presentation at 2000 Conference on Information Sciences and Systems, Princeton University, Princeton, NJ, Mar. 15-17 2000.

9. I. N. Psaromiligkos and S. N. Batalama, "Data record size requirements for adaptive antenna arrays," participation/presentation at SPIE's 14th Annual International Symposium, Digital Wireless Communication Conference, Orlando, FL, April 2000.

10. G. N. Karystinos and D. A. Pados, "Multiuser differential-PSK demodulators for DS/CDMA signals," participation/presentation at SPIE's 14th Annual International Symposium, Digital Wireless Communication Conference, Orlando, FL, April 2000.

11. J. D. Matyjas and S. N. Batalama, "A Regularized MVDR-filter Estimator with Application to DS/CDMA Communications," participation/ presentation at ICT 2000, Acapulco, Mexico, May 22-25, 2000.

12. D. A. Pados, "Recovering the phase of blind space-time DS/CDMA channel estimates," participation/presentation at ICT 2000, Acapulco, Mexico, May 22-25, 2000.

13. D. A. Pados, "A sequence of MVDR filter estimators," participation/presentation at ICT 2000, Acapulco, Mexico, May 22-25, 2000.

14. I. N. Psaromiligkos and S. N. Batalama, "Finite data record performance analysis of rapid synchronization and combined demodulation algorithms," participation/presentation at ICASSP2000 - Int. Conf. Acoust., Speech and Signal Proc., Istanbul, Turkey, June 5-9, 2000.

15. S. N. Batalama and I. N. Psaromiligkos, "Data record size requirements of MVDR-optimized adaptive antenna arrays," participation/presentation at ICASSP2000 - Int. Conf. Acoust., Speech and Signal Proc., Istanbul, Turkey, June 5-9, 2000.

16. D. A. Pados and G. N. Karystinos, "Short-data-record estimators of the MVDR/MMSE filter," participation/presentation at ICASSP2000 - Int. Conf. Acoust., Speech and Signal Proc., Istanbul, Turkey, June 5-9, 2000.

17. I. N. Psaromiligkos and S. N. Batalama, "Blind self-synchronized demodulation of DS-CDMA communications," participation/presentation at IEEE International Conf. on Communications (ICC 2000), New Orleans, LA, June 18-22, 2000.

18. I. N. Psaromiligkos and S. N. Batalama, "Finite data record maximum SINR adaptive space-time processing," participation/presentation at IEEE SSAP2000 - Workshop on Statist. Signal and Array Proc., Pocono Manor, PA, Aug. 14-16, 2000.

19. I. N. Psaromiligkos and S. N. Batalama, "Interference-plus-noise covariance matrix estimation for adaptive space-time processing of DS/CDMA signals," participation/presentation at IEEE VTC2000 - Vehicular Tech. Conf., Boston, MA, Sept. 24-28, 2000.

20. H. Qian and S. N. Batalama, "Data-record-based criteria for the selection of an auxiliary-vector estimator of the MVDR filter," participation/presentation at 34th Asilomar Conf. on Signals, Systems, and Computers, Pacific Grove, CA, Oct. 29 - Nov. 1, 2000.

## II. Consultative and advisory functions to laboratories and agencies

1. S. N. Batalama, "Robust adaptive recovery of spread-spectrum signals with short data records", Seminar (2 hours), U.S. Air Force Research Laboratory, IFGC, Rome, NY, Sept. 17, 1999.

2. S. N. Batalama, "Adaptive robust spread-spectrum receivers and their application to GPS - Part I", Seminar (2 hour 30 min) U.S. Air Force Research Laboratory, IFGC, Rome, NY, June 16, 1999.

3. S. N. Batalama, "Adaptive robust spread-spectrum receivers and their application to GPS - Part II", Seminar (2 hour 30 min) U.S. Air Force Research Laboratory, IFGC, Rome, NY, June 17, 1999.

4. S. N. Batalama, "Blind self-synchronized demodulation of DS-SS Communications", Seminar (3 hours), U.S. Air Force Research Laboratory, IFGC, Rome, NY, June 24, 1999.

5. S. N. Batalama, Summer Research Faculty, U.S. Air Force Research Laboratory, IFGC, Rome, NY, May 1999 - July 1999.

6. S. N. Batalama, "Adaptive robust spread-spectrum receivers and their application to GPS", Seminar (1 hour), Naval Air Warfare Center, China Lake, CA, Feb. 1, 1999.

7. S. N. Batalama, "Spatial and temporal processing of GPS signals", Seminar (2 hours), U.S. Air Force Research Laboratory, IFGC, Rome, NY, July 11, 2000.

### III. Transitions

1. Performer: S. N. Batalama

Customer: Dr. Michael J. Medley, [IFGC, AFRL, Rome, NY, telephone: (315) 330-4830, e-mail:medleym@rl.af.mil]. Results: Spread-spectrum receivers - Methods for adaptive protection from non-Gaussian disturbances and unknown correlated spread-spectrum interference with limited input observations. Applications: Robust adaptive SS receivers, robust adaptive SS receivers with antenna arrays, adaptive jam-resistant GPS.

2. Performer: S. N. Batalama

Customer: Dr. Michael J. Medley, [IFGC, AFRL, Rome, NY, telephone: (315) 330-4830, e-mail:medleym@rl.af.mil]. Results: Adaptive GPS array receivers - Methods for jam resistant navigation data demodulation employing space-time interference suppression techniques. Applications: GPS navigation and GPS guided delivery.